Call for applications for admission to XXXVIII Cycle of Politecnico di Bari PhD Programmes

Attachment 5

PhD PROGRAMME IN ENGINEERING AND AEROSPACE SCIENCES

Inter-university course in collaboration with University of Bari "Aldo Moro"

Project Identification Code (CUP): D93C22000550001; D93D22001360001

XXXVIII CYCLE DOCTORATE PROGRAMME PROFILE	
DEPARTMENT	Department of Mechanics, Mathematics and Management
COORDINATOR	Prof. Marco Donato de Tullio (marcodonato.detullio@poliba.it)
PLACES AVAILABLE	13
of which	
Places with Politecnico di Bari grant	2
*Places with **Politecnico di Bari grant reserved for graduates from non-Italian universities***	1
*Places with **Uniba** grant*	3
*Places with grant funded by NRRP – as per Ministerial Decree **351/2022*** ***Refer to research topic list below***	2 of which: GRANT N.1 - **Area**: NRRP; **Topic**: "*Viscoelastic materials for the storage and transport of Green Gel Fuels*"; GRANT N. 2 - **Area**: NRRP; **Topic**: "*Specifics and verification of software systems in the field of aerospace using formal methods*".
*Places with grant funded by NRRP – as per Ministerial Decree **352/2022*** ***Refer to research topic list below***	2 of which: GRANT N.3 - **Co-funded by**: Astradyne s.r.l..; **Topic: "***Modelling and design of origami-inspired deployable structures for aerospace applications"*; GRANT N. 4 - **Co-funded by**: Thales Alenia Space Italia s.p.a.; **Topic: "A** *Digital Twin for integrated photonic circuits"*;
Places without grant funding	3
ADMISSION REQUIREMENTS *Applicants to the PhD programme in Engineering and Aerospace Sciences **must hold a second level (specialized) degree***	➢ Degree diploma awarded by the Italian university system prior to Ministerial Decree 509/99; ➢ Specialist Degree (as per Ministerial Decree 509/99); ➢ Master's Degree (as per Ministerial Decree 270/04); ➢ Degree qualifications awarded by foreign universities officially recognised as equivalent[1].

[1] *Where a qualification awarded by a foreign university **has not yet been declared equivalent** to an Italian university degree, subject to verification by the administration offices, the Selection Committee will decide upon the eligibility of the foreign qualification in line with current Italian regulations and those of the country of origin, as well as any international treaties or agreements on qualification recognition for further study.*

APPLICATION PROCEDURES	
Please note that the information provided below complements and does not substitute that contained in arts. 2 and 3 of the general Application Call.	
REQUIRED DOCUMENTATION *Candidates must upload the following documentation to their online application.* ***Failure to do so will result in their exclusion from the selection procedure****.*	➢ **A CV** following the layout of the example provided by Politecnico di Bari at https://www.poliba.it/it/dottorati-di-ricerca. *(File to be named "01.CV")*. ➢ **Copy of a current identification document**. Only the following documents will be considered eligible: • ID cards issued by an EU member state; • driving licence issued by an EU member; • in all other cases, a full validity passport (also non-EU citizens). ➢ **Degree qualification certification for first (Bachelor's) degrees and second (specialization/Master's) degrees (or 5-year Single Cycle degrees**. **Candidates with qualifications awarded in Italy** must attach the Politecnico form available at https://www.poliba.it/it/dottorati-di-ricerca, specifying: • final degree mark; • a list of all exams taken with their relative marks in both degree courses (or the Single Cycle course); • results of exams taken. *(File to be named "03.Titoli di Laurea")*. **Candidates with a degree qualification awarded by a non-Italian university** must attach the following documents to their application, as issued by the awarding body. This supersedes any form of self-declaration [2]: • Degree certificate or diploma showing relative final mark; • Official transcript of exams taken during all university study programmes, showing relative results; • Any other type of document which demonstrates the equivalence of qualifications with those required in this application call (Supplementary Diploma, *Dichiarazione di Valore* (statement of value) issued locally. *(File to be named "03.Titoli di Laurea")*. ➢ **An abstract of the thesis topic for specialist/Master's degree (or five-year Single Cycle degree),** stating the title and name of thesis supervisor(s) (max 3,000 characters).

[2] **N.B.**: These documents must be in Italian, French or English or translated into Italian or English and verified by an official Italian diplomatic or consular representative under the responsibility of the candidate. These should follow the guidelines set out in the document "*PROCEDURES FOR ENTRY, RESIDENCY AND ENROLMENT OF INTERNATIONAL STUDENTS AND THE RESPECTIVE RECOGNITION OF QUALIFICATIONS, FOR HIGHER EDUCATION COURSES IN ITALY FOR THE ACADEMIC YEAR 2022/23*" available at the Ministry link https://www.studiare-in-italia.it/studentistranieri/".

	(File to be named "04.Abstract Tesi"). ➢ **Candidate thesis for specialist/Master's degree (or five-year Single Cycle degree)** For **graduating students** whose thesis is not yet complete (see art.2), a draft version of the thesis which has been completed up to the time of application; (**N.B.** "draft version" implies a version of the thesis text as completed by the graduating candidate up to the date of application, which, in terms of chapters and pages, allows the Selection Committee to evaluate its relative content and subject area. The abstract is uploaded as a separate file and is not considered as a draft version of the thesis under any circumstances. *(File to be named "05.Tesi")*. ➢ **PhD research** proposal which the candidate intends to develop during the programme, stating the scientific basis of the proposal, its research objectives and the methods to be used (maximum 9,000 characters). Research proposals and projects are assessed purely for the purposes of admission and are not necessarily those which the candidate will follow during the programme. **Research proposals must use the format available at the following link (title "*ALLEGATO E_FORMAT PROPOSTA DI RICERCA_DRISA.doc*"):** **https://www.poliba.it/sites/default/files/dottorati/allegato_e_format_proposta_di_ricerca_drisa_english_0.docx.** **N.B**: Candidates who intend to propose a research project based on the topics set out in Ministerial Decrees 351/2022 and 352/2022 must prepare a proposal in line with one or more of the topics listed below. *(File to be named "06.Proposta di Ricerca").*
OPTIONAL DOCUMENTATION	➢ **A self-certification declaration for any other qualifications** deemed suitable for evaluation which must be signed and dated (following the layout of the example provided at https://www.poliba.it/it/dottorati-di-ricerca), as per arts.46 and 47 of Presidential Decree n. 445/2000. *(File to be named "07.Dichiarazione altri titoli")*. ➢ **Either one or two letters of reference from teaching staff** who have supervised the candidate throughout their university-level studies. *(Files to be named "08.Lettera presentazione 1", "08. Lettera presentazione 2")*. ➢ **Language certification** demonstrating a knowledge of English which corresponds to at least B2 level. Only those candidates who are non-Italian citizens may attach certification which demonstrates knowledge of the Italian language.

	(File to be named "09.Certificazione linguistica 1"; etc). ➢ **Any publications** related to activity carried out and shown on the candidate's CV. These must be in either Italian or English or translated into Italian or English on behalf of and under the responsibility of the candidate. In cases of **large publications** unavailable in electronic format or which exceed the number of MB permitted for documents, applicants may submit these separately (in paper format or as a CD or DVD-ROM), together with a detailed explanatory list, by 2 p.m. on the deadline date for applications. All publications submitted on paper or on electronic media must be sent in a sealed envelope, signed along the flap, to the following address: Magnifico Rettore del Politecnico di Bari – Direzione Gestione Risorse e Servizi Istituzionali - Settore Ricerca, Relazioni Internazionali e Post-Lauream - Ufficio Protocollo – Via Amendola 126/B, 70126 BARI (Italy). Envelopes must show the name and surname of the candidate together with the following text: "*Concorso di Ammissione al Corso di Dottorato in…* (name of the PhD programme)". The delivery of the envelope containing publications to Politecnico di Bari – by postal service, private courier or shipping agency – is wholly at the candidate's risk. *(File to be named "10.Pubblicazione 1"; etc*).
DOCUMENT CHECKLIST	**<u>Required documentation:</u>** ➢ **CV** *(to be named "01.CV"*); ➢ **Copy of a current identification document** *(to be named "02.Documento Riconoscimento"*); ➢ **Degree qualification certification for first (Bachelor's) degrees and second (specialization/Master's) degrees (or 5-year Single Cycle degrees)** *(to be named "03.Titoli di Laurea"*); ➢ **Abstract of the thesis topic for specialist/Master's degree (or five-year Single Cycle degree)** *(to be named "04.Abstract Tesi"*); ➢ **Candidate thesis for specialist/Master's degree (or five-year Single Cycle degree)** *(to be named "05.Tesi"*); ➢ **PhD research proposal** (*to be named "06.Proposta di Ricerca").* **<u>Optional documentation:</u>** ➢ **Self-certification declaration for any other qualifications** *(to be named "07.Dichiarazione altri titoli"*); ➢ **Either one or two letters of reference from teaching staff** *(to be named "08.Lettera presentazione 1", "08. Lettera presentazione 2"*);

	➢ **Language certification** *(to be named "09.Certificazione linguistica 1"; etc*); ➢ **Any publications** *(to be named "10.Pubblicazione 1"; etc).*

ADMISSION EXAMINATION	
1.ASSESSMENT OF QUALIFICATIONS HELD	Assessment of qualifications held (average exam scores, final degree mark, theses, Master's degrees, post-graduate courses, language certification, publications, etc.).
2. ASSESSMENT OF RESEARCH PROPOSAL	
3. INTERVIEW	The interview provides an opportunity for a complete evaluation of the candidate and a verification of the applicant's aptitude for research and willingness to undertake experience abroad, as well as areas of research interest
DATES OF INTERVIEWS	Tuesday 20 Sept 2022; Wednesday 21 Sept 2022; Thursday 22 Sept 2022; Friday 23 Sept 2022.
The Examination Board will assess candidates' qualifications and interview with a mark **out of 100** (maximum mark for qualifications 20, research proposal 20 and interview 60). Candidates awarded less than **10 marks** for the **qualification evaluation** will not be admitted to the research proposal phase of the selection process. The minimum pass mark for the **evaluation of the research proposal** is **10**. The minimum pass mark for the **interview is 30**. **The minimum overall pass mark for the selection procedure is 50.** The results of the Board's assessment for qualifications and research proposals will be published on the Esse3 portal in the private area of each candidate. No other direct notification will be sent to the candidates. At the end of the examination procedure, the Board will carry out an overall assessment and draw up an admission rankings list on the basis of the marks obtained by candidates in each part of the examination. The assessment criteria for qualifications will be established by each Examination Board.	

LIST OF RESEARCH TOPICS FOLLOWS

Finanziato dall'Unione europea
NextGenerationEU

GRANT N.1 DRISA
D.M. 351/2022
Area: PNRR
Topic: “Storage and transportation of green fuels via viscoelastic materials (GreenGelFuels)”

RESEARCH PROPOSAL:

Gel fuels currently consist of alcohol and cellulose ether as a thickener, resulting in a gel fuel that burns cleanly, generates a small amount of soot, is virtually smoke-free, and limits the production of harmful combustion products. Furthermore, from the propulsive point of view, the viscoelastic structure of the gels allows the suspension of metal particles, thus increasing both the specific impulse and the energy density. The viscoelastic properties have the advantage of reducing possible accidental spills, thus increasing safety. Gel propellants can exhibit both shear-thinning and shear-thickening. [1] Generally, the apparent viscosity of the gel increases with the addition of gelling agents which makes the fuel more difficult to atomize and more difficult to achieve high combustion efficiency. Very little is known about the combustion characteristics of gels and the phenomena involved have not yet been fully understood. [2]
The gelling agents' presence can affect combustion in various ways: (i) the melting temperature of the gel increases with the concentration of the gelling agent; (ii) the heat of gelling varies with the concentration of the fuel type in the gelling system. [1] Consequently, the heat of vaporization should also be influenced, which in the combustion of droplets is a rather significant parameter, however, the effects of the content and type of gelling agent on its final value are not known. In this research project, viscoelastic matrices (gels) will be developed using green materials, such as cellulose, ionic liquids, and/or biocompatible polymers to create trapping systems for sustainable fuels with high efficiency.
The green fuels that will be examined are of the biodiesel type, i.e. a renewable and biodegradable fuel produced internally from vegetable oils, animal fats, or recycled fat. Biodiesel is both a biomass-based diesel and a renewable fuel. Renewable diesel is commonly referred to as "green diesel" or "green diesel". Green diesel, one of the alternative energy products, is a second-generation biofuel, which has a similar molecular structure to petroleum diesel but provides better properties. Green diesel is produced by hydrotreating triglycerides in vegetable oils with hydrogen [3]. The Boeing Company is seeking approval to use a green diesel blend as an alternative to Jet-A for turbine aircraft.
In this project, the effect of different green types of diesel will be tested on the appropriate viscoelastic matrices, i.e. gels, in order to obtain a system with performance characteristics both from a mechanical and from a combustion point of view (GreenGelFuels).
The gel rigidity is due to the presence of a network formed by the interconnection of particle structures. The nature of the particles and the type of force are responsible for the interconnection and determine the properties of the gel. In the case of hydrophobic colloidal particles, these can be quasi-spherical in shape or be isometric aggregates, which, interacting with lotus, form the gel [4]. In linear macromolecules (polymers) the network consists of the intersection of the same macromolecules, the contact points, and entanglements, between them, can be relatively small or consist of several molecules aligned in crystalline order. Polymer chains can form entanglements by means of a covalent bond, for example, a network formed by crosslinking polymer chains or by non-linear polymerization. Alternatively, the entanglements can be due to the physical aggregation of polymer chains, caused by hydrogen bonds, crystallization, helix formation, complexation, etc. The resulting swollen network can be defined as a "thermoreversible gel" in the case of entanglements are thermally reversible. [5,6]
Currently, my research group has a stress-controlled rotational rheometer capable of characterizing the mechanical performance, i.e. the viscoelastic characteristics, of gel systems. In addition, tools for the

determination of heat of combustion such as thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) are available at the department of Chemistry (University of Bari). GreenGelFuels can be heated in air or oxygen at normal pressure up to 900 ° C and kept isothermal until the weight change due to the loss of combustion gases ends. The weight loss phases allow you to check for other processes in addition to combustion, for example vaporization, and whether constituents such as moisture and ash are present in the material. Therefore, the exothermic DSC measurement of combustion can be related to specific weight losses.

To characterize the structure of the gel from the supramolecular point of view, an external collaboration (period abroad of the PhD student) and eventually large-scale facilities will be settled. The approach for the structural characterization can take place with both microscopic techniques and techniques based on X-ray, Nuetron or light scattering.

From an operational point of view, the doctoral student will be placed within the PhD in Engineering and Aerospace Sciences (DRISA), an inter-university doctoral program that involves the Polytechnic of Bari and the University of Bari Aldo Moro. The internships of the research program are as follows:

1. Formulation of green diesel-based viscoelastic systems.

The PhD student will begin his research work with the preparation of different types of gels based on cellulose, methylcellulose and / or block co-polymers loaded with green diesel from different renewable or recycled sources.

2. Mechanical characterization of gel systems

The gel systems obtained will be characterized from a mechanical point of view [7]: (i) classifying the gels as dilating (shear-thickening), yield-pseudoplastic, pseudoplastic, or Bingham plastic-type (shear-thinning) on the basis of the respective flow curves obtained from stationary experiments; (ii) oscillatory measurements to determine the variation of the elastic modulus with respect to the loading of the green diesel . The proponent (prof. Luigi Gentile) is an expert in rheological characterization with over 20 articles and two book chapters on the subject.

3. Determination of the combustion properties and combustion residues

Each of the prepared gel systems will be subsequently characterized in terms of fuel performance and residue release by DSC and TGA. Any residue will be analyzed using FT-ATIR, NMR, and other analysis techniques to determine the presence of any non-eco-sustainable material.

4. Structural characterization of gel systems.

Finally, the doctoral student will carry out the structural characterization during the period abroad. Evaluating the structure of the polymer gels requires a structural analysis at the molecular and supra-molecular levels. It is known that various physical gels from semi-crystalline polymer solutions form a higher-order positioning in a polymer chain. Furthermore, in the sorting process of polymers, such as gelation or crystallization, the ordering of the molecular conformation is critical. Microscopy is one of the most useful methods for gaining knowledge about these processes. In complementary terms, scattering can be useful in determining the mesh size of gel systems. The interaction between the polymer and the solvent in the gel-forming process is also an important issue, however, information about this interaction can also be obtained. PNRR areas: Climate, energy and sustainable mobility. Future Energy Scenarios. Others: Space-related activities.

[1] G. Nachmoni and B. Natan, Combustion Science and Technology, 156, 2000, 139-157.
[2] Y. Solomon, B. Natan, Y. Cohen, Combustion and Flame, 156, 2009, 261-268.
[3] M. Fahmi Othman, A. Adam, G. Najafi, R. Mamat, Renewable and Sustainable Energy Reviews, 80, 2017, 694-709.
[4] L. Gentile, G. De Luca, F. E Antunes, C. Oliviero Rossi, G. A. Ranieri, Applied Rheology, 20, 2010, 52081.
[5] RG Jones, J Kahovec, R Stepto, ES Wilks, M Hess, T Kitayama, WV Metanomski, IUPAC Recommendations 2008. RSC Publishing, Cambridge, UK.
[6] S Slomkowski, JV Alemán, RG Gilbert, M Hess, K Horie, RG Jones, et al., Pure and Applied Chemistry. 83 (12): 2229–2259.
[7] L Gentile, S Amin, Chapter 11 in Colloidal Foundations of Nanoscience (Second Edition), Elsevier, 2022, https://doi.org/10.1016/B978-0-12-822089-4.00003-9.

Finanziato dall'Unione europea NextGenerationEU

GRANT N. 2 DRISA
D.M. 351/2022
Area: PNRR
Topic: “Specification and verification of software systems in the aerospace sector with formal methods”

RESEARCH PROPOSAL:

Context of reference

Formal methods represent a vast set of mathematically rigorous techniques for specifying, developing, and testing software and hardware systems. They include computer science fundamentals such as logical and symbolic computation, formal languages, automata theory and program semantics. The use of formal methods in systems design activities is motivated by the assumption that, like what occurs in other engineering disciplines, the logical-mathematical analysis of system properties contributes to making design more robust and reliable, especially for those so-called critical systems that are typical, for example, of the aerospace domain. In fact, it is no coincidence that these methods have historically been introduced in the field of Software Engineering, a computer engineering specialization born in the late 1960s on the occasion of the Apollo 11 space missions.

Research theme

As already mentioned, formal methods apply to problems of specification, development and verification of software and hardware systems.

In this research project we will focus to software systems only, considering in particular the case of "security-critical" systems that incorporate "intelligent" components, namely components based on the application of Artificial Intelligence (AI) techniques. The vulnerabilities of these systems, made particularly critical by the disruptive potential of AI, will be analyzed with reference to some real or realistic scenarios of interest for the aerospace sector. At the same time, some formal methods suitable for specifying and / or verifying the robustness of these systems from a safety point of view will be reviewed. Since the choice is very wide, it is planned to restrict the search to those based on logical and symbolic calculation, in order to leverage the common roots between Computational Logic and the so-called symbolic AI. This affinity in fact enables the application of a wide range of techniques, methods, and tools, for the modelling of systems (with or without AI modules) and for the verification of the adherence of the model to a certain property. In particular, the verification can be formulated as a constraint satisfaction problem, and be implemented following the typical approach of Computational Logic which involves the use of a solver based on automatic theorem proving algorithms. Among the various alternatives, Answer Set Programming (ASP) stands out as one of the most recent and promising evolutions of Computational Logic, which provides efficient automatic solvers for declarative problem solving problems. This feature allows us to abstract from the procedural details of the system being modelled, or to focus attention on what the system must do rather than how it must do it.

The project therefore presents itself as an interesting and challenging combination of research, not necessarily only applied, between (formal methods for) Software Engineering, Artificial Intelligence, and Cybersecurity, with Aerospace as the preferred application domain. These are strategic areas for the scientific and technological development of the country, and therefore the project proposal can be considered relevant for the purposes of the PNRR. The innovative aspect of the research is the use of formal methods deriving from Computational Logic.

Educational / professionalizing objectives

The project aims to train highly qualified researchers and professionals able to tackle very complex IT problems and define highly reliable solutions, especially in terms of security. These problems appear in advanced technological sectors that design or maintain software not only in the aerospace industry but also in other fields such as telecommunications, air transport, metropolitan networks, high-speed rail transport, automotive industry, energy supply networks, etc. Furthermore, issues such as safety are transversal to all these fields and represent the various challenges in the current landscape.

Opportunity for national and international collaboration

The proponent of the project has been carrying out basic and applied research activities for more than 20 years in Artificial Intelligence and Computational Logic. She is well integrated in the reference communities for these two sectors both nationally and internationally (organization of conferences of sector, participation in the governing bodies of sector scientific associations, etc.). In particular, she has been an elected member of the Board of the Italian Association for Artificial Intelligence since 2013. She teaches formal methods for security at the Master's Degree in Information Security at the Taranto branch of the University of Bari. He is a member of the Board of Professors of the PhD in Aerospace Engineering and Sciences, a consortium between the Polytechnic of Bari and the University of Bari. She has contacts with a foreign research centre on aerospace systems engineering specializing in safety and reliability.

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GRANT N.3 DRISA
D.M. 352/2022
Co-funded by: Astradyne s.r.l..
Topic: "Modelling and design of origami-inspired deployable structures for aerospace applications"

RESEARCH PROPOSAL:

The deployable structure consists of the combination of basic structural units, such as rods, cables and membranes. Since the deployable structure in space has the ability to realize the transition from a tightly folded state to a controllable deployable state, it is becoming the primary means of resolving the contradiction between the large structures of spacecraft and the volume of the envelope of space launchers. Large-scale, lightweight, high-precision deployable structures have been widely demanded in the fields of deep space/lunar exploration, astronomical high-resolution astronomical/earth observations and space solar power plants.

To meet the performance requirements of large-scale lightweight and high-precision space, deployable structures face some new technical challenges in the aspects of design, analysis, and measurement. One technical challenge is the design of new deployable structural shapes to reduce the total weight, which is usually accompanied by new design methods and modeling of the mechanisms, as well as the application of new materials. As a large-scale space, deployable structures have the characteristics of wide, flexible and strong nonlinearities, reliable deployment and high-precision retention in complex space environments are other technical challenges. The solutions of these technical challenges require proposing a series of special methods of analysis, measurement, control vibration and so on. In addition, emerging on-orbit assembly technology bring some additional technical challenges in addition to the challenges mentioned above.

Potential topics include but are not limited to the following:

- Design and analysis of deployable mechanisms
- Performance optimization of deployable structures
- Deployment dynamics of deployable structures, such as space deployable antennas, solar array, membranes
- Passive and active control methods in structural vibration
- Reliability analysis for the deployment and structural performance
- In-orbit assembly methods, including module design, interface design, assembly sequence planning, and control methods
- Thermal control of deployable structures
- Static and dynamic analysis of deployable structures
- Testing methods on the ground, such as gravity unloading, gravity compensation, thermal test
- In-orbit measurement methods for static surface/shape and dynamic responses of deployable structures

GRANT N. 4 DRISA
D.M. 352/2022
Co-funded by: Thales Alenia Space Italia s.p.a.
Topic: “Digital Twin of Integrated Photonic Circuits”

RESEARCH PROPOSAL:

a) Research theme and coherence with the National Strategy for Intelligent Specialization (SNSI) approved by the European Commission

The aim of the research is to develop new design approaches for the realization of high-performance integrated photonic circuits, according to the digital twin paradigm, for the development of next generation systems for the Space domain. The proposal is fully in line with the SNSI thematic areas Intelligent and Sustainable Industry, Energy and Environment (theme: Innovative high-efficiency production processes for industrial sustainability, Evolutionary Production Systems for customised production) and Aerospace and Defence (theme: Advanced Avionics in the field of hw modules networks and human-machine interface, Earth Observation Systems, in the field of missions, instruments and data processing), as well as with the goal of developing enabling technologies such as Photonics and Micro/Nanoelectronics, Advanced Materials and Nanotechnology and Advanced Manufacturing Systems.

b) Proposed research activities, methodologies and contents

A digital twin system is a virtual replica of a complex system developed to help in managing its performance, production and costs. Such a replica is powered by appropriate programmes that use real-world data to model a product and produce a digital output that mimics the physical behavior of that object. In 2017, Gartner Inc. listed digital twins as one of the top 10 strategic technology trends and predicted that billions of systems would have digital twins over the next decade. Since then, the related market has grown exponentially with an annual CAGR of over 30% approaching $10 billion in 2021. Digital twins are currently used in several domains, from large physical size projects such as buildings and aircraft production to manufacturing and adaptive engineering. In parallel, there is a trend to move the concept of digital twins to subsystems or complex components that may represent critical elements of larger systems with the growing need for digital twins to be increasingly accurate and close to reality. For instance, in electronics, digital twins need to provide an all-inclusive representation of components parameters and behavior, becoming an important tool in the design of chips of increasing complexity where the development of 'fast' and true-to-life models, together with a better communication throughout the supply chain, also speeds up time-to-market. Following this global trend, the impact of the digital twins on optics and photonics is growing and is leading to a paradigm shift in concepting and designing of photonic circuits and systems.

The proposed research activity falls within this specific field of application of digital twins, with the ambition of making a relevant contribution to its development. In particular, the research will focus on the development of digital twins of photonic systems for Space (strategic subsystems and payloads) with the innovative aspect of starting from the characterization and knowledge of foundry processes for the main material systems used for photonic devices and circuits, enabling a smart and adaptive design and a consequent predictive assessment of the systems' behavior that also takes into account the stringent operating and environmental conditions in Space.

c) Degree of innovation in the research proposed for the area of intervention

The use of simulations is well known in the field of engineering and thus also in electronics and photonics. Several powerful but often specialized simulation approaches can be used to successfully investigate specific problems and address the design of photonic systems of increasing complexity. However, when the focus is on the process engineering, this 'classical' simulation methodology results in a discontinuous, time-consuming, expensive process that is affected by errors and specific conditions. When developing complex systems, consisting of a variety of devices and subsystems, it is necessary not to forget the big picture, and this leads to the use of a new simulation approach within the real system with the development of 'mental models', which provide a basis for the development of conscious and intelligent systems. Compared to 'classical' simulation and design approaches, using digital twins that take into account the real characteristics of both the production process of components and systems, as well as specific environmental conditions, drastically changes the point of view on simulation technology, with the demand to flexibly combine and exchange different aspects between different sizes, with the multiple result of significantly reducing the effort (time, costs, data loss, errors) to create a simulation application, to use different simulation applications (or parts of them), to quickly switch between different applications, to develop simulation applications that cannot be realized so far.

d) Consistency of the research topic with the subject area of the doctorate and the composition of the teaching board

The proposed research topic is fully consistent with the disciplinary field and the goals of the PhD program, which aims to train, also through a heterogeneous composition of the teaching staff, experts with a high scientific profile in the aerospace field and able to work on highly complex systems, with strong interactions among scientific, technological, economic and social aspects, through an organization in three interconnected cultural fields such as Aerospace Engineering ("classical" topics including the study of aerospace structures, fluid-dynamics, flight mechanics and aerospace propulsion), Aerospace Systems (information technologies related to new aircraft and new space missions), Aerospace Sciences (topics of experimental physics of cosmic radiation, high energy, innovative materials and sensors, plasma chemistry-physics, as well as management and space economy topics).

Electronics (ING-INF/01) is one of the scientific-disciplinary sectors consistent with the educational objectives of the PhD program in Aerospace Engineering and Sciences at the Politecnico di Bari. Optoelectronics and Photonics fully fall within the research topics in the larger Electronics field, where there is a strong interest in the applications of microelectronic, nanoelectronic, micro-electro-mechanical, optoelectronic and photonic devices and systems to Space. Therefore, photonics for Space is fully within the scope of the PhD program.

e) Technical feasibility of the proposal and schedule

The research will be carried out in collaboration with the research group of Dr. Georg Pucker (Fondazione Bruno Kessler, FBK, Trento), Professor Williams (Technical University of Eindhoven) and Thales Alenia Space Italia. Dr. Pucker is the head of the research unit on Advanced Materials and Photonic Structures at FBK's Center of Materials and Microsystems and has extensive experience in the development of silicon (Si) technology processes and the design of integrated photonic devices. Prof. Kevin Williams is a full professor and head of the photonic integration research group at Eindhoven University of Technology. His main fields of expertise include photonic integrated circuits, in indium phosphide (InP) and InP-Si hybrid technology. For more than 40 years, Thales Alenia Space has been designing, integrating, testing and operating innovative high-tech space systems for telecommunications, navigation, Earth observation, environmental management, scientific research and orbital infrastructure. Thanks to its highly advanced know-how in dual-use civil/military missions, satellite constellations, flexible payloads, altimetry, meteorology, and radar and

high-resolution optical instrumentation, Thales Alenia Space is internationally recognized as a leading company in its market sector.
Politecnico di Bari (Prof. Ciminelli's research group) has a long-standing and well-structured cooperation with the research groups and the company involved, thanks also to previous joint research projects, with consequent benefits on the technical feasibility of this initiative.
The research will be organized according to the following steps:

- Review of research topics (month 1 to month 8)
- Definition of the theoretical framework (month 6 to month 33)
- Development of demonstrators to support the proposed framework (month 8 to month 33)
- Validation and revision of the framework through real case studies (month 18 to month35)
- Doctoral Thesis writing (month 31 to month 36)

It is believed that the stay at Eindhoven University of Technology could take place during the second year of the PhD studies (for a duration of 6 months) and the stay at Thales Alenia Space partly during the first, second and again the third year (for a total duration of 18 months).
Collaboration and interaction with the Eindhoven University of Technology, Thales Alenia Space and also the Bruno Kessler Foundation will in any case extend throughout the duration of the PhD studies.

f) Synergies with respect to the possible employment of PhDs (in relation to the world of work)

The knowledge gained during the PhD course on the topics of the Digital Twin and photonic technologies, which, as already explained, impact on several areas, is of high value and relevance for highly specialized professional profiles already in great demand on the job market. The skills developed can be applied not only in the Space domain, but are transversal and successfully applicable in many areas of the National Strategy for Intelligent Specialization.